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FACTORS WHICH INFLUENCE THE QUANTITY OF PROTEIN IN WHEAT[1]

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Protein in wheat has a definite meaning when applied to the quantity obtained by an approved chemical method. The importance of quantity of protein is emphasized at the present time by the premium paid for high protein wheat. Quality is a characteristic more difficult to define. However, in bread wheat a good quality usually accompanies high quantity.

Quality of protein in wheat should be judged in accordance with the use to be made of the flour. Quality in hard wheat used for making bread with yeast as the leavening agent, is different from quality in soft wheat used for making bread with chemicals liberating carbon dioxide as the leavening agent. Durum wheat contains a high per cent of protein, but the quality is not such as is desired for making bread flour.

Both practical experience and experimental evidence have shown that the protein content of wheat is influenced by several factors which are at the same time interacting, and conclusions can not be drawn from the action of any one factor without at the same time considering other related factors. It is also true that factors which affect quantity also affect quality.

Influence of Climate

Climate is usually considered to have a greater influence upon both the quality and the quantity of protein in wheat than any other factor. Climate includes a variety of factors, the most important of which are:

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Rainfall, both amount and distribution, temperature, wind velocity, and evaporation. A climate having dry winters, cool springs with moderate rainfall, and hot, fairly dry summers usually produces a hard, strong wheat characterized by a high protein content. A climate of more open winters with a high rainfall in spring and summer produces a soft wheat or one characterized by yellow-berry and a relatively high starch content. As weather or climatic conditions vary from year to year, higher or lower protein wheat, characterized by more or less strength, may in different years be produced in the same area. The conclusion of the tri-state experiment reported by LeClerc (8) was that climate was such a dominant factor in influencing the composition of wheat that soil and seed play only a small part.

Influence of Rate of Ripening

One of the most apparent ways in which climate influences the protein content is by its effect on the rate of ripening. That immature kernels have a higher protein content than those fully mature has been shown by Failyer and Willard (1891), Kedzie (1892), and Brenchley and Hall (1909). From their experiments it has been inferred that a rapid rate of ripening results in a higher protein percentage. Thatcher (15, 16) has shown that the most important factor is the rate of protein gain in relation to gain of carbohydrates. He found that before and in the early milk stage the carbohydrates were deposited relatively faster than the protein, but later this relation was reversed. This confirms the work of Teller (1898), who found that the proportion of total nitrogen in the dry matter of the wheat kernel steadily decreased from the time it was formed up to about a week before ripening, but from this time on the proportion of nitrogen increased. The experiments, showing in some cases that immature kernels have a higher per cent of nitrogen than those fully matured, and in other cases that the reverse holds true, are somewhat contradictory. This can be explained only on the ground that the rate of development is influenced by several opposing factors, the final result depending on which factor is dominant. Two of these factors are the amount and the concentration of the soil solution, as will be shown in a following paragraph.

Influence of Variety

That variety has an influence on the protein content of wheat is evidenced by the success with which wheat breeders have developed new varieties which consistently contain higher per cents of protein than other varieties. While the influence of variety is secondary to that of climate and probably also to that of soil, experiments have

shown that certain varieties under the same conditions of climate and soil will produce a higher per cent of protein than other varieties, as shown by Shaw and Gaumnitz (1911).

Influence of Irrigation

It is usually considered that wheat grown under irrigation has a lower protein content than wheat grown with no irrigation. This is partly because the application of water permits the development of a large crop, and partly because irrigated wheat is grown on raw sage brush land poor in nitrates, as indicated by the data published by Jones, Fishburn and Colver (1920). If irrigated land is well supplied with nitrates the character of the wheat will be hard and flinty. This was emphasized by Headden (1918).

Importance of Available Soil Nitrogen

The importance of available nitrogen in the production of high protein wheat has until recently not received as much attention as climatic factors. That the protein content of wheat may be increased by methods of cultivation (Olson, 1917) and by the addition of nitrates (Davidson and LeClerc, 1917) has been shown. The time of application is also important, according to Neidig and Snyder (1922). The greater part of the soil nitrogen is absorbed before the time of heading, as shown by Snyder (1903), hence applications made during the more active stages of growth have a greater effect in increasing the protein content of wheat than those made during the milk stage.

Relation of Yield to Protein Content

Much has been said about the importance of high protein wheat, but very little is mentioned in regard to yield. It should be very evident that quantity of protein produced per acre is as important as quantity of protein per bushel, if not more so. Wheat may have a high percentage of protein, but that may mean a low yield of protein per acre if the crop is small, and wheat may have a lower percentage of protein but a high yield of protein per acre if the crop is large. Medium high yields with a comparatively high protein content usually mean large yields of protein per acre. Lyon (1905) found in his experiments at the Nebraska Agricultural Experiment Station in 1900 that the percentage of total nitrogen was 3.02, the yield 33 bushels per acre, and nitrogen 52.75 pounds per acre. In 1901 the percentage of nitrogen was 2, the yield 39.5 bushels per acre, but the yield of nitrogen was 43.04 pounds per acre.

Experiments at the Kansas Agricultural Experiment Station

A study of the factors which influence the quality of wheat, is the major project of the Department of Milling Industry. The work is done in co-operation with the Department of Agronomy. Tables I, II, and III summarize some of the data relating to the quality of the wheat produced with different systems of cropping, tillage, and fertilization at the agronomy farm, Kansas Agricultural Experiment Station.[2] The wheat in these tests is grown under two general systems of soil treatments. In one system the effect of fertilizers in various combinations is studied. In one series wheat is grown continuously, in another it is grown in a 3-year rotation with cowpeas and corn, and in a third in a 16-year rotation with corn and alfalfa. In the other system the effects of various methods of tillage and seedbed preparation are investigated. Listing the ground and disking without plowing as compared with plowing, and the time and depth of plowing, are some of the methods that are compared.

Table I gives the average yield and protein content for 10 years from different fertilizer treatments when wheat is grown continuously and in rotation. The protein content is uniformly lower in the wheat from all the plots in the 3-year rotation. In this series the wheat was grown after cowpeas and these plants continue to grow to within a short time of wheat seeding, which means a low content of available nitrogen in the soil when the plants start growth. The protein content of the wheat from the plots in the 16-year rotation and from those cropped continuously to wheat is not materially different. The figures do not show any consistent relation between protein percentage and yield. The highest average yield in the 16-year rotation is 22.6 bushels and this plot also gives the highest average protein content. In the continuous wheat series the highest average yield is 21 bushels, and the corresponding protein percentage is next to the lowest. In the 3-year rotation the highest yield of 26.9 bushels has next to the highest protein percentage. In each case the highest yield in bushels also produced wheat with highest yield in pounds of protein per acre. No definite conclusion is drawn from the effects of the different fertilizer treatments on protein percentage.

In Table II the average of all the treatments is given for each year. The data taken in connection with those in Table I show at once that the seasonal fluctuations are very much greater than those due to different soil treatments. However, years of high yields do not always have low protein wheat. In the continuous wheat series

[2] The writer is under obligation to L. E. Call, R. I. Throckmorton, and M. C. Sewell for the yield data secured in these experiments.

the lowest yield, 6.90 bushels, was obtained in 1918 and in this year the protein percentage of 21.80 was the highest, but the pounds of protein per acre was the lowest. The highest yield (33 bushels) of this series was obtained in 1922. In this year the protein percentage was the lowest, but the yield of protein per acre was the highest for any of the ten years.

In the 3-year rotation the lowest yield, 11 bushels, was obtained in 1913, and in this year both the percentage and the yield of protein per acre were the lowest for the ten years. Where wheat followed cowpeas in this rotation the percentage of protein was lower in every year as compared with the plots in continuous wheat.

In the 16-year rotation the highest average yield, 36.6 bushels, was obtained on the plots which grew after wheat. The percentage of protein was next to the lowest, while the yield of protein per acre was within two places of being the highest in the 16-year rotation plots. The highest yield of protein per acre was obtained in 1914 when the yield was next to the highest. In this year the protein percentage was above the average. In this rotation, in which wheat followed corn, the protein content was higher than in the 3-year rotation in seven years of the ten.

From the data in Table II it may be pointed out that: (1) The years in which the highest yields have been secured may be years in which the wheat has the lowest percentage of protein, but at the same time the highest yield of protein per acre; (2) the years characterized by low yields may be characterized by the highest protein percentage, but the lowest yield of protein per acre; (3) years of medium high yields are likely to have wheat of high protein content and high protein yields per acre; (4) methods of rotation will influence the protein content to such an extent that one system of rotation will give, in a series of years, a consistently higher percentage of protein than another system, in spite of seasonal fluctuations.

In the seedbed preparation plots, data from which are presented in Table III, the highest yields were obtained in 1913 and 1914, and in these years the protein content was the lowest. The lowest yields were obtained in 1916, but the percentage of protein was not very high, being exceeded in four other years. It is at once evident that the soil treatments in July and August have given the largest yields, a higher percentage of protein, more protein per acre, and a larger loaf volume than the treatments in September. Loaf volume is one of the most significant factors in measuring quality in wheat. While these differences in loaf volume would not be considered large if they

TABLE I

PERCENTAGE OF PROTEIN AND YIELD OF GRAIN AND PROTEIN PER ACRE; FERTILIZER AND ROTATION EXPERIMENTS; AVERAGE FOR TEN YEARS

	Continuous wheat			Three-year rotation			Sixteen-year rotation		
	Yield per acre, bushels	Protein, per cent*	Protein per acre, pounds	Yield per acre, bushels	Protein, per cent*	Protein per acre, pounds	Yield per acre, bushels	Protein, per cent*	Protein per acre, pounds
Phosphorus	21.0	17.30	192.5	22.9	14.29	173.4	21.8	17.67	203.7
Check	17.6	17.76	165.7	20.9	14.78	163.7	19.1	17.59	178.2
P and K.....	19.2	16.67	169.6	21.8	14.06	162.4	21.5	17.44	198.5
Potassium	15.5	18.83	154.8	18.5	14.95	146.6	....	.....	.....
Check	14.1	18.65	139.4	16.3	15.23	131.6	18.6	17.60	173.1
N, P, and K.....	17.5	18.87	175.1	22.5	15.60	186.0	22.6	18.53	222.0
Manure	19.6	17.35	180.2	26.9	15.23	217.1	21.9	17.44	203.3
Average	17.8	17.92	186.8	21.4	14.98	168.7	20.9	17.71	196.3

*Calculated on moisture-free basis.

TABLE II

PERCENTAGE OF PROTEIN AND ANNUAL YIELDS OF GRAIN AND PROTEIN PER ACRE; FERTILIZER AND ROTATION EXPERIMENTS, 1913 TO 1922

	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	
										Series I	Series II
Continuous Cropping of Wheat											
Yield per acre, bushels.....	19.00	24.30	23.30	10.60	14.70	6.90	22.60	13.10	10.20	33.00	.....
Protein, per cent*.....	18.37	17.82	18.47	14.83	16.80	21.81	16.79	19.12	18.11	13.88	.....
Protein per acre, pounds.....	185.00	229.50	228.10	83.30	130.90	79.80	201.10	132.80	97.90	242.80	.....
Three-Year Rotation											
Yield per acre, bushels.....	11.00	30.80	19.10	19.80	13.20	15.10	22.30	11.80	21.20	26.00	.....
Protein, per cent*.....	12.94	16.58	19.74	14.50	16.66	15.90	13.19	16.39	14.95	13.08	.....
Protein per acre, pounds.....	75.40	27.10	199.80	152.20	116.60	127.20	155.90	102.50	168.00	180.20	.....
Sixteen-Year Rotation											
Yield per acre, bushels.....	15.60	33.70	23.30	22.20	10.80	12.80	20.90	13.90	18.20	36.60†	26.50‡
Protein, per cent*.....	12.55	17.19	19.74	16.85	18.20	17.69	17.88	23.81	14.90	13.21	18.81
Protein per acre, pounds.....	103.80	307.00	243.80	198.30	104.50	120.40	197.90	174.90	143.60	256.20	263.50
Wheat Seedbed Preparation or Tillage											
Yield per acre, bushels.....	22.80	24.40	16.50	8.20	14.60	10.40	18.70	12.30	8.90	17.60	.....
Protein, per cent*.....	12.67	12.48	15.28	13.93	14.67	17.63	13.93	16.49	14.52	12.63	.....
Protein per acre, pounds.....	153.10	161.40	133.20	60.50	113.20	97.20	138.00	107.10	68.50	117.80	.....

*Calculated to a moisture-free basis. †After wheat. ‡After corn.

represented results for any one year, they can be considered very significant as they are the averages for 11 years. Thus better methods of seedbed preparation result not only in higher yields per acre and higher percentages of protein but also in better quality.

TABLE III

RELATION OF SEEDED PREPARATION TO YIELD AND PROTEIN CONTENT OF WHEAT AND LOAF VOLUME OF FLOUR; AVERAGE FOR 11 YEARS

Soil treatment	Yield per acre, bushels	Protein, per cent	Protein per acre, pounds	Loaf volume, cc.
Disked at seeding	7.7	13.84	56.6	1801
Plowed in September	11.4	13.88	83.6	1834
Plowed in August	16.8	15.19	135.5	1882
Plowed in July	16.4	15.85	138.1	1874
Listed	16.5	15.97	139.8	1870
Double disked in July, plowed in September	16.3	15.97	138.2	1859
Double disked in July, plowed in August	16.1	16.88	144.2	1916

The highest protein content and the best quality is produced from varieties adapted to the climatic conditions of the wheat growing region. Considerable work has been done at the Kansas Experiment Station in comparing Kanred, a strain of Turkey hard wheat, with other strains of this variety. The average of nine crops grown at Manhattan, Kan., gives the following figures for yield and protein content of Kanred in comparison with Turkey.

Variety	Yield per acre, bushels	Protein, per cent	Protein per acre, pounds
Kanred	29.5	16.17	253
Turkey	26.4	15.83	222

Discussion and Summary

Nitrogen, the most important element in the protein molecule, comes from the available nitrogen of the soil, hence high protein wheat is possible only if the supply of this element is ample. The bulk of the soil nitrogen is in an insoluble or unavailable form, but it is made soluble slowly by the agencies existing in the soil, and the rate of this production of available nitrogen is one of the factors which determine the protein content of wheat. As soon as nitrogen is made available it appears in the soil solution. The amount of this soil solution is determined by the moisture supply. The concentration of soluble nitrogen in this soil solution is determined by the rate at which nitrogen is made available and the amount of the solution. In the presence of a large supply of moisture, the rate of formation of soluble nitrogen must be greater than when the supply of moisture is smaller, if the same concentration is to be maintained. Concentration of soil solution

in available nitrogen and the amount of this solution are the two most important factors which determine yield and protein percentage. Climate owes its importance to the fact that it is the greatest factor influencing the soil solution.

Plowing land for winter wheat in July does two things, it prevents weed growth and makes the conditions for bacterial activity or formation of available nitrogen more favorable. If weeds are allowed to grow, much of the available nitrogen is stored in the weeds and less is left for the young wheat plants. An ample supply of available nitrogen at the time of seeding starts a large vegetative growth and if this supply is maintained during the whole growing period, a large yield of high protein wheat is the result; provided that this high concentration of available nitrogen is maintained in the presence of an optimum amount of moisture, a sufficiency of other essential elements, and other favorable growth factors. There seems, however, to be a limit to the amount of protein which can be formed, as the highest yields are usually accompanied by lower protein percentages than medium or low yields.

If the conditions for the production of available nitrogen are favorable and the moisture supply is limited, a low yield of high protein wheat is obtained. The later stages of growth have the highest moisture requirements. A limited supply of moisture at this time usually means a high concentration of available nitrogen, hence the possibility of a high protein wheat. This condition of limited moisture supply exists when wheat is grown under dry land conditions, hence such wheat is usually high in protein but low in yield. The opposite conditions are usually found when wheat is grown under irrigation. The ample supply of moisture usually means a low concentration of available nitrogen. Conditions are favorable for the production of a large yield, but the amount of nitrogen is too limited for the production of a high protein wheat at the same time.

If the growth factors are favorable during the early stages of the life of the wheat plants, large vegetative growth starts; and if these continue favorable during the life of the wheat, a large yield will result. If nitrogen is the limiting factor the wheat will be low in protein; if the nitrogen supply is ample the wheat will be high in protein. While a large amount of nitrogen is absorbed from the soil by the plant during the early stages of growth, the time between head formation and ripening is a critical period. Cool weather during the fruiting period and an ample moisture supply usually mean a soft yellow berry or starchy wheat. Cool weather is less stimulating to the production of available nitrogen, and ample moisture supply means

a low concentration. Thus while the yield is high the protein content is low. A small yield of low protein wheat results when other growth factors are more limiting than the nitrogen. The other most common factor is moisture. Thus if wheat is growing under conditions of a low concentration of available nitrogen, and there is a sudden desiccation by hot winds, a low yield of light weight and low protein wheat results.

The two factors, concentration and amount of soil solution, may vary during the growing season and from year to year, and for this reason there are years of high yields and high protein percentage; years of high yields and low protein percentage; years of low yields and high protein percentage; and years of low yields and low protein percentage. Also in the same years, different areas, fields, and plots may differ in the same ways because of the inter-relation of the effects of the quantity and concentration of the soil solution.

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A PRACTICAL APPLICATION OF THE VISCOSIMETER TO THE MILL

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(Read at the Convention, June 13, 1924)

We have historic evidence that the human race has consumed leavened bread as one of its chief articles of diet for about two thousand years, but it has remained for the twentieth century scientist to delve into the problems underlying its production. At an early period of these investigations, we find mentioned, by comparison, a good flour, also a strong and a weak flour. We, as millers of flour, want to ascertain what constitutes this good flour. To our mind a good flour is one which will make a good loaf of bread under almost any method of handling. Many such flours are milled today, that is, flours which both the average baker and the cereal chemist (if unbiased) will unqualifiedly recommend.

In our research we have sought for some dependable means of testing wheat which would foretell the character of the resultant flour. Formerly, the miller was chiefly interested in the physical characteristics of the wheat and the cleanness and granulation of his flour. If he could chew the wheat up into a good gum, grind it fine enough "to stick upon the wall," and bolt the bran specks from it, he was satisfied. Later a white color became the dominant factor. Then, following the advent of the chemist for routine work, came the crude gluten (by washing), ash, protein, acidity, experimental milling, and baking tests.

The last named became and still is the most used and best criterion of flour quality, but presented many objectionable features. As Blish (citation) has well outlined, it required too much time and an operator of considerable skill. For these reasons it was very difficult to control, and when unfavorable results were attained did not explain the underlying causes. Many operative millers have advocated the baking test alone in passing judgment upon a flour, and the chemist has turned to the analytical data in an attempt to explain its success or failure. All these tests, both physical and chemical have proved inadequate and we are still searching, preferably, for some one test, for a quality flour, until many of us have come to believe that such a test is a utopian idea.

It is true that experience has taught us many things. We have found that hard wheat flours were more easily made into bread and soft wheat flours into pastries. Low-ash flours usually indicated a lower extraction or cleaner milling. Wide geographical blending usually improved the quality of the flour from any type of bread wheat. Since the advent of the commercial chemist the layman has come to believe that high protein wheat would invariably make a high quality flour. This was natural, and merely another application of "a little knowledge is a dangerous thing." The experienced miller and chemist found that high protein wheat usually could be milled into high quality flour, but always exercised judgment in the choice of such wheat, realizing fully that the protein content was only one of a number of factors that must be considered. Most of us have been guilty of milling a high-protein flour to satisfy a prevalent demand and found it necessary to buy high-protein wheat. This demand or a lack of supply caused a market price for such wheat that was all out of proportion to its intrinsic value.

We, as milling chemists, were naturally interested in the recent investigations of hydrogen-ion concentrations and viscosity measurements of flour suspensions, and their possible significance to routine mill work. The theoretical investigators in this field have made many wonderful discoveries and we seem to be emerging from the darkness which has masked our former efforts. Let us hope it may be in the power of the practical men to make suitable application of this newer knowledge. A knowledge based upon sound scientific principles.

Two years ago we chose the viscosimeter as the most suitable means for determining flour quality and since that time have made use of this instrument in all our routine work. In our preliminary work with this instrument we found that good flours gave on the whole relatively high viscosities, whereas mediocre or poor flours gave

relatively low viscosities. We also found that most flours, including our own, showed greater variations in viscosity than they did in any other of the analytical tests. Our endeavor was to produce a flour of uniformly high viscosity. We also found that viscosity measurement could be made on the whole wheat meal and that high-viscosity wheat could be milled into high-viscosity flour.

Needless to say the methods in use by the research laboratories for viscosity determinations were physically and economically impossible for routine work. It was necessary to make a very rapid determination with the minimum of expenditure for equipment and no extra man power. Our method in detail consisted of:

Weighing out on the analytical balance, 22.5 grams of flour, air dry basis, into a half-pint cream bottle. On the general assumption that flour contained 12.5 per cent of moisture, we had 20 grams of dry flour. We added 100 milliliters of distilled water, at 35°C. and by aid of a spatula stirred it into a smooth suspension. We digested for one hour, at room temperature, with occasional shaking. We introduced 5 milliliters of normal lactic acid solution, stirred thoroly with a spatula, poured into the large bowl, and immediately determined the viscosity with the MacMichael viscosimeter, at a bowl speed of 20 revolutions per minute, using a No. 27 copper wire and the large disk bob, reading the index as soon as the bob became constant.

Care must be taken that no air bubbles form under the brass disk, hence we churn the solution for a second or two prior to suspending the wire. The position of the wire (longitudinally) once standardized, must not be changed. We usually set the lower end of this wire flush with the chuck. The original idea of this procedure was to obtain the maximum swelling of the gluten colloids. Present indications are that we must adopt the use of a still stronger acid if we expect to overcome the higher buffering of some flours and wheats. However, for correlating control work, we found that the swelling with 5 milliliters of normal lactic acid was ideal and possibly more nearly represented the actual conditions of the average dough batch than the maximum swelling range.

To our mind, lactic acid was the best medium of suspension, because the imbibitional curve made a uniform rise and the maximum, once attained, was more stable than most other acids or alkalies.

We consider that a good so-called patent flour suspension should read 90° MacMichael, a straight flour, 80° M., and a clear flour, 60° M.

For wheat meal we followed the same procedure, except that we added only 65 milliliters of water. This amount of water was arbitrarily chosen as it gave a suspension of suitable mobility. Branny

particles were scrapped down into the solution with the point of the spatula and the wheat meal was not shaken up during digestion. We found it first necessary absolutely to reduce the wheat to a floury state, and therein lay our greatest difficulty. We used Arcade flour mills (power driven) and made two or three reductions. If the wheat was a little damp and the burrs were set too close, the stock had a great tendency to flake and "ball up" the burrs with the evolution of much heat. If the wheat was not properly reduced, the viscosity measurements ran too high. In our opinion, a sample of hard winter wheat which made from 45 to 60° MacMichael by the above process would make a flour of good gluten quality, irrespective of protein, or test weight.

Our first endeavor was to determine good and poor wheat growing areas, to segregate and eliminate the poor wheat unavoidably received, and so to classify and blend our available stocks as to secure a uniform standard mill mix as regards protein, viscosity, and test weight. This it was readily possible to do, but we still found viscosity variations in our flour and it did not seem possible that this was due entirely to ordinary milling variations, consequently we went to work on the mill streams. We found the instrument would work on coarse middlings as well as on flour, and we made some very interesting discoveries.

Most millers make a so-called patent flour. Originally this flour was made only from purified middlings, that is, the break flour, and tailings stocks were not included. With the improvement of milling machinery it was possible to increase this middlings flour from the original 25 or 30% to the 65 or 75% of the best mills of today. Many mills have classified these various streams on baking test alone and such classification has frequently been very successful from the empirical standpoint, but many chemists and millers too have been concerned with ash and protein, or color and dress to the detriment of the total possibilities of the flours.

The terms I use may not be very explicit, but possibly you can draw an analogy in other mills. In a four-break nine-reduction mill, we found that first, second, third, and fourth middlings seemed to show an ascending order of viscosity, as was to be expected, but we found sizings middlings gave a very low viscosity, while sixth middlings and cut sections showed a high viscosity. We could not explain this. The only factor that came to our minds was that these sizings contained much germ stock as they were sent to the roll, and knowing the usual poor quality of that flour dusted from the germ section, we wondered if this wheat oil could have a detrimental effect. These sizings usually ran about 0.45% of ash, and 10% of protein,

but when the miller had reduced the ash to 0.35% and practically removed the germs, the viscosity was still low. The sixth middlings and cut sections (fine-break middlings) were both dirty and had a high ash content. They were cleaned up and still gave a high viscosity, consequently were placed in the patent flour while the sizings were placed with the clear stocks.

We purchase our wheat on the basis of viscosimeter tests. We believe we get results by our method. We know it is very crude. We are dealing with only one class of wheat (hard winter) and our practical judgment guides us as to its soundness. As you will note, we make no attempt to wash out the salts that are present. We have no standards except empirical ones for the fineness of the whole wheat meal or for the viscosimeter, consequently we do not attain results that are completely trustworthy. Our variations may run as high as 5° MacMichael. We can check between our own laboratories, but we do not expect to check with other chemists under our method. At present we certainly do not favor the establishment of a viscosity test on wheat by state grain testing laboratories. Some grain men are advocating this and in time it may come, but first we must create a standardized method, and it is our hope that this exposition may, in some small way, attribute to that ideal. Protein and viscosity do not necessarily seem to go together, altho in all probability there will in time be worked out a protein, viscosity, test-weight ratio, which will be of material advantage in the choice of wheat. Our grain buyers contend that they can pick out high viscosity wheat by the eye, much as they and the elevator men guess at the protein content. It is the idea of one of them that such wheat has a "silver-gray sheen," if you know what that means.

In conclusion, we would not care to attempt to run a laboratory without a viscosimeter, and we hope it will be only a short time until this machine has a permanent place in every mill. I believe we all desire to develop the best possible loaf of bread from the wheat we have to grind, for better bread is the only means to increased consumption, and we believe that the viscosimeter quickly and surely points out real gluten quality in both wheat and flour, and thus eliminates many of the inconsistencies of the gluten cup and the old baking tests.

CARBON DIOXIDE DIFFUSION RATIO OF WHEAT FLOUR DOUGHS AS A MEASURE OF FERMENTATION PERIOD

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Various methods have been employed in dough fermentation practice to control the length of the fermentation period. A method recently suggested involves fermenting all doughs until they attain a certain hydrogen-ion concentration. Such a procedure would of necessity involve a substantial reduction in the length of the fermentation period of doughs made from high-grade or patent flours whose hydrogen-ion concentration had been increased in consequence of (a) lapse of time in storage, (b) bleaching with chlorine, or (c) acidulation at the time of mixing the dough. Practical baking experiments have shown that such reductions as would be necessitated in treatments "b" and "c" if hydrogen-ion concentration were the sole criterion of the length of the period, result in less satisfactory loaf characteristics than extending the period to more nearly the normal. In other words, there are definite limitations on the extent to which the fermentation period may be shortened by increasing the hydrogen-ion concentration of the dough. Again, doughs made with the lower grade or clear flours require a materially longer fermentation period than patent flour doughs in order to bring them to the same pH as is attained by the latter in normal fermentation. The clear flours are buffered more than the patent flours, and, as shown by Bailey and Sherwood (1923), the hydrogen-ion concentration of doughs made with the former increased much more slowly than did that of doughs made with the latter. When clear flour doughs were fermented long enough to bring them to the same pH as fermented patent flour doughs, not only was the bread inferior to that fermented for a shorter period, but the loss in dry matter, owing to the extended fermentation, was about doubled. There is a sound basis in theory for the conclusion that bringing doughs to a definite pH will not necessarily result in satisfactory bread, but the discussion of this reasoning will be reserved for a later paper.

In commercial practice the time allowed for the first rise of a straight dough has in many instances been determined by a simple test involving the insertion of a finger into the dough, which is regarded as

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ready to "punch" if the dough recedes or tends to "fall." In certain shops the time to the first punch constitutes about 60% of the total fermentation period. After such preliminary testing of doughs made from any lot or blend of flours, a time schedule for doughs similarly compounded could be laid out, and adhered to so long as all conditions, including yeast activity, remain uniform. Generally speaking, a dough which responds to the test described has about reached its maximum volume. As shown by Bailey and Weigley (1922), the fermenting dough loses carbon dioxide much more rapidly at this point than at any previous stage. This is probably because of the rupturing of vesicles at the surface which are filled with carbon dioxide. It accordingly appears probable that this sudden increase in the rate of loss of carbon dioxide from a dough marks a definite stage or condition which may be correlated with the optimum fermentation period. Observations of bakery practice, and of small-scale baking tests have indicated that the types of doughs which give the best results with a relatively short fermentation likewise show this explosive discharge of carbon dioxide from rupturing vesicles after a short interval of fermentation. Thus a soft red winter wheat straight-grade flour which is in the optimum state for producing the best possible bread, when fermented for a shorter time than hard spring wheat patents are fermented likewise gives off carbon dioxide at an accelerated rate earlier than the latter. Yet the winter wheat straight flour dough increases in hydrogen-ion concentration more slowly than the spring wheat patent, and if the fermentation period were adjusted on the basis of time required to reach a predetermined pH, it would require a longer instead of a shorter time than the latter. Because of the apparent significance of this suddenly increased rate of loss of carbon dioxide from dough, which marks a certain period in the cycle of changes incident to fermentation, an effort was made to evolve a convenient and simple method for determining when this state is reached.

The method first used by Bailey and Weigley (1922), while accurate, proved somewhat cumbersome and impractical for use in the bake-shop. The time required to make observations on a few doughs necessitated the continuous attention of a skilled analyst. Two distinctly different devices were subsequently developed and employed in the experiments here reported, both of which proved very useful and comparatively simple of operation. They were used to the exclusion of the earlier and more complicated method.

In the first of these two methods, the expansion of the dough was observed under two sets of conditions. An aliquot of a freshly mixed dough representing the equivalent of 50 grams of flour was placed in

a shallow beaker, which was inserted within a perforated waxed paper cylinder. The beaker in turn was placed in a mason jar. With the jar in an upright position, 100 cc. of 23% sodium chloride solution was introduced in such a manner that none of it entered the beaker containing the dough. A sodium chloride solution of this concentration is in hygroscopic equilibrium with an atmosphere of 80% relative humidity, and hence built up a humidity in the vessel high enough to keep the surface of the dough from forming a hard crust. The mason jar was then closed with a cover which was provided with a metal

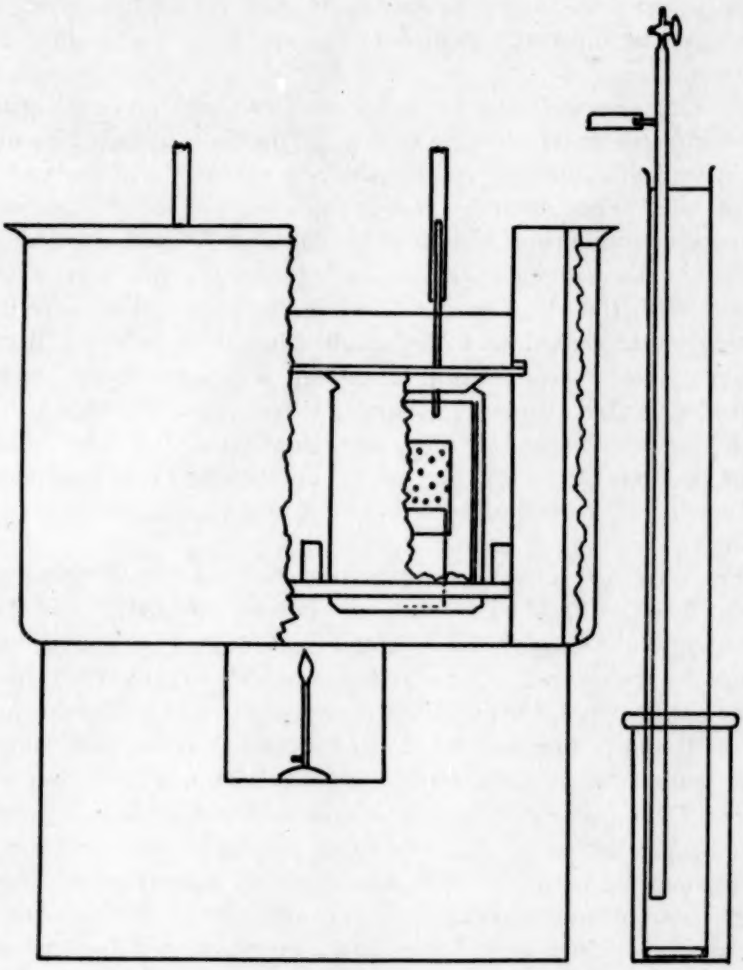

Fig. 1. Apparatus Through the Use of Which the Increase in Volume of the Dough, the Volume of CO_2 Lost from the Dough, and the Sum of These Two Volumes Were Obtained

tubulure soldered into an opening made for the purpose. This tubulure in turn was connected to an inverted burette by means of heavy-walled tubing. The arrangement of the several parts of the device is shown in Figure 1. The burette was inverted in a large glass tube which was filled with saturated common salt solution. As the dough fermented, its increase in volume plus the volume of escaping carbon dioxide, registered in terms of liquid displaced in the burette. As liquid was displaced, the burette was elevated in such a way that the level of the salt solution was the same inside and outside of the burette, thus maintaining atmospheric pressure within the mason jar and communicating tubes. As shown in the figure, the jar and contents were maintained at constant temperature by immersing the jar in a water thermostat.

Another identical set-up was provided in which an equal quantity of dough was under observation except that in this case the mason jar, instead of containing sodium chloride solution, was charged with 100 cc. of 23% potassium hydroxide solution. The latter is likewise in hygroscopic equilibrium with an atmosphere of 80% relative humidity, so that in this particular the atmospheres in the two jars were the same. With the alkali present, and through the aid of a collar of blotting paper wetted with the alkali solution, it followed that the carbon dioxide escaping from the dough was immediately absorbed. Thus the volume change registered by the burette connected to this second jar represented only the expansion of the dough. The difference in the readings of the first and second burettes was thus equivalent to the volume of carbon dioxide which had escaped from the dough during the interval in question.

In a typical experiment involving the study of a hard spring wheat patent flour with ash and nitrogen contents of 0.41% and 1.81% respectively, the data given in Table I and graphed with solid lines in Figure 2 were secured. Curve A represents the progressive expansion of the dough plus the volume of the escaping gas. In this case, and in Curves B and C, time in minutes is plotted as abscissas, and volume in cubic centimeters as ordinates, the latter being noted at the left of the figure. From Curve A, which approximates a straight line, it is evident that the production of carbon dioxide continued at a uniform rate throughout the period of the experiment (4 hours) even after the dough had practically ceased to expand. Curve B represents the volume of the dough as registered in the jar which contained potassium hydroxide solution. Expansion of the dough continued fairly uniformly during the first 150 minutes, after which it slowed down, owing to the rupturing of the surface vesicles containing the carbon dioxide

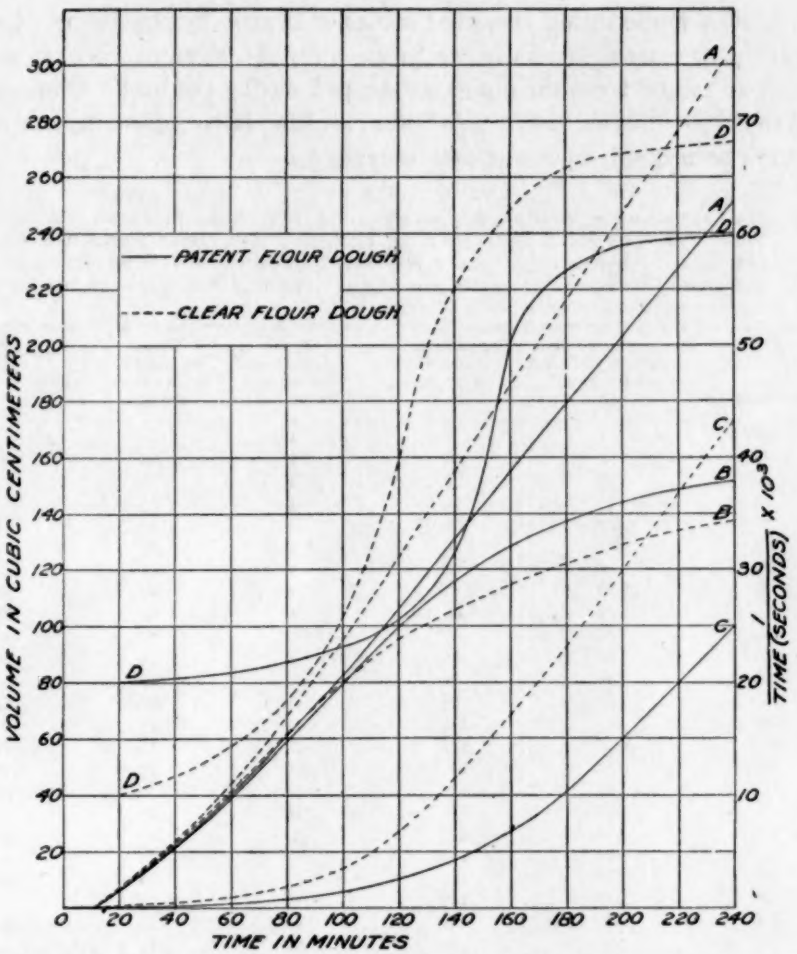

Fig. 2. Changes in Volume Which Occur in Systems Containing Fermenting Patent and Clear Flour Doughs

Curves A represent the sum of the increase in volume of the dough and the carbon dioxide lost from the dough. Curves B, the increase of the dough; Curves C, the volume of carbon dioxide lost from the dough. Curves D, plotted from data obtained through the use of the Osterhout apparatus, show sharp breaks at the point at which the vesicles of the dough surface are no longer able to hold the carbon dioxide.

of fermentation. The difference between the values recorded in Curves A and B is recorded in Curve C, which accordingly represents the volume of carbon dioxide that escaped from the dough. Curve C particularly engages our attention. Evidently the loss of carbon dioxide from this dough was relatively small during the first 140 minutes. The 15 cc. of carbon dioxide which had escaped up to this time is equivalent in weight to 2.965 milligrams, or 0.06% of the weight of the flour. Between the 140th and the 160th minute (a mean

of 150 minutes) this rate of loss, as indicated by the shape of the curve, increased decidedly, requiring only 24 minutes for as much CO_2 to escape from the dough as escaped during the first 140 minutes. After 160 minutes the rate of loss became fairly constant, and the curve accordingly approximates a straight line.

TABLE I

INCREASE IN VOLUME OF THE DOUGH, VOLUME OF CO_2 LOST FROM THE DOUGH, THE SUM OF THESE TWO VOLUMES AS DETERMINED AT 10-MINUTE INTERVALS THROUGH THE USE OF THE VOLUME APPARATUS, AND, SIMULTANEOUSLY, TIME IN SECONDS FOR THE COLOR CHANGE TO OCCUR AS DETERMINED THROUGH USE OF THE OSTERHOUT APPARATUS AND THE RECIPROCAL OF THAT TIME—FLOUR B 932 (PATENT)

Time Minutes	Increase in volume of dough + CO_2 lost from the dough cc.	Increase in volume of the dough cc.	CO_2 lost from the dough cc.	Time required for color change Seconds	$\frac{1}{\text{Time}} \times 10^3$
10	0	0	0	..	....
20	4	4	0	50	20.0
30	10	9	1	50	20.0
40	18	16	2	55	18.1
50	27	26	1	50	20.0
60	37	33	4	45	22.2
70	48	42	6	45	22.2
80	58	52	6	40	25.0
90	69	63	6	40	25.0
100	82	77	5	40	25.0
110	94	86	8	35	28.5
120	106	96	10	35	28.5
130	117	106	11	40	25.0
140	131	115	16	35	28.5
150	143	123	20	35	28.5
160	156	130	26	20	50.0
170	167	134	33	15	66.6
180	179	139	40	20	50.0
190	192	140	52	15	66.6
200	204	143	61	15	66.6
210	217	146	71	10	100.0
220	227	148	79	15	66.6
230	238	149	89	20	50.0
240	249	150	99	15	66.6

When dough made from a clear grade flour, with an ash and nitrogen content of 0.85% and 2.13%, respectively, was subjected to a similar study, the data represented by the broken-line curves in Figure 2 were obtained. There were several differences in the behavior of the patent and clear flour doughs. The production of CO_2 in the latter was at a higher level throughout the entire 140 minutes, as is evident from the difference between the two curves marked "A." This may be due to a number of factors, including a higher initial sugar content, diastatic activity, and soluble phosphate content of the clear grade flour dough. The clear flour dough expanded slightly faster at the outset, but after 120 minutes this advantage disappeared and thereafter it expanded less rapidly than the patent dough. The most striking differences in the properties of these two doughs are evident on com-

paring the two curves marked "C," which represent the loss of CO_2 from the doughs. In case of the clear flour dough the break in the shape of the curve, denoting an acceleration of the rate of loss of CO_2, appears between the 100th and 120th minute (a mean of 110 minutes), or 40 minutes earlier than in the patent flour dough. Attention should also be called to the fact that in case of the clear flour dough the loss of CO_2 becomes so great after 200 minutes that it exceeds that retained by the dough, a condition not reached in the patent flour dough after 240 minutes of fermentation. This emphasizes the statement made in a foregoing paragraph—that extended fermentation of such clear flours is wasteful because of the loss of carbohydrates which are converted into CO_2 and alcohol and thus lost as nutrients from the finished bread. Baking experiments justified the conclusion that doughs made from such clear grade flours, also from soft winter wheat flours which likewise lost CO_2 at an accelerated rate earlier in the fermentation period, could be converted into better bread by reducing the fermentation period in like proportion, using a strong patent flour as a basis of comparison, than when their fermentation was extended. Yet the rate of change in pH of the clear flour dough was so much slower, and its initial pH so much higher than the patent flour dough that it would have required about 10 hours for the former to reach the pH which the patent flour dough had reached at the end of the fifth hour.

The second method used to determined the comparative rate of loss of CO_2 from dough was even simpler in operation than the first, altho the apparatus included more parts. It involved the use of the device employed by Osterhout (1917) in studying the rate of respiration of plants, with such modifications as were necessary to adapt it to our requirements. Osterhout's apparatus consisted of a closed system through which the enclosed air was circulated and the respired CO_2 was absorbed in a faintly alkaline solution. This solution contained a sensitive indicator, phenol red (phenol-sulfone-phthalein), which changed from red to yellow with the increase in hydrogen-ion concentration resulting from the absorption of carbon dioxide. The time required for a definite change in pH (from 7.8 to 7.0) of this solution constituted a convenient measurement of the rate of liberation of CO_2 into the atmosphere of the container. The change in pH was determined by comparing the color of the solution in the absorbing vessel with that of two buffered solutions containing phenol red and having a pH of 7.8 and 7.0 respectively. Time was recorded in seconds as noted by means of a stop-watch. The dough under observation was placed in a cylinder of paraffined wire gauze. This in turn was inserted into

an inverted mason jar which was closed with a rubber stopper. The arrangement is shown in Figure 3. The stopper was provided with two openings, through one of which a tube was passed which extended above the dough in the cylinder. The air circulating in the system entered the jar through this tube. The second opening in the stopper admitted the outlet tube, through which the gases were withdrawn from the jar. This tube was cut off level with the inner face of the stopper, and a small cylinder of wire gauze was connected to it in

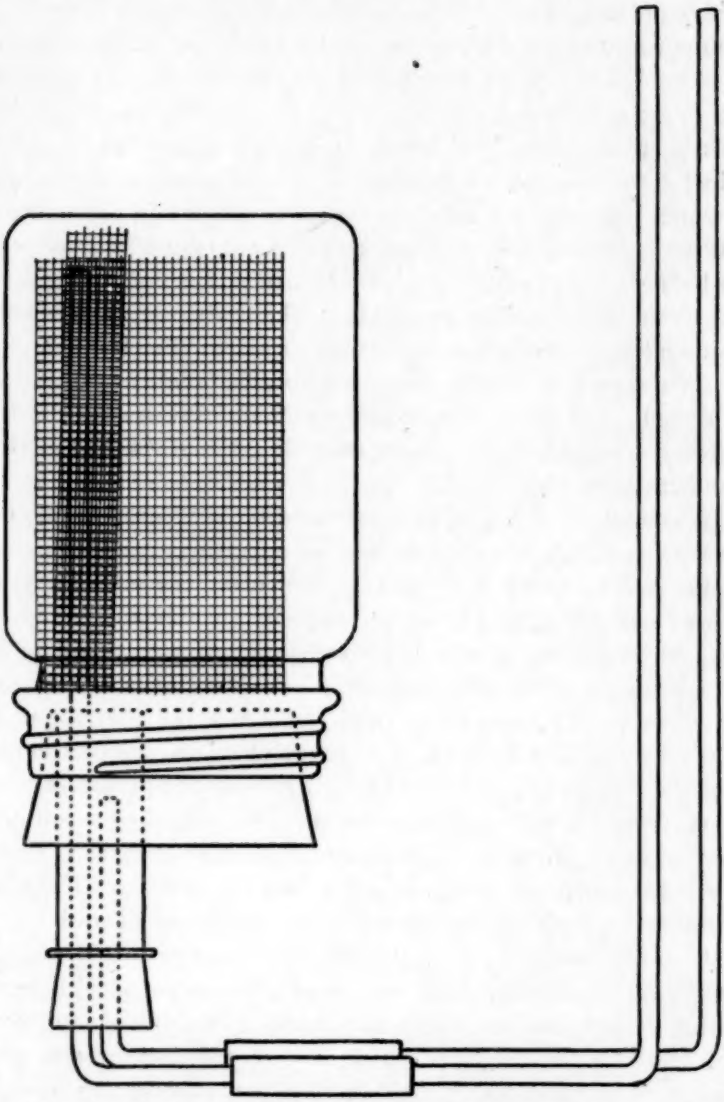

Fig. 3. Dough Container Used in Connection with the Osterhout Apparatus

such a way as to keep the outlet open as the dough expanded. As the shape of the mass of dough was a factor in affecting the comparative loss of carbon dioxide, an effort was made to have this uniform in all cases. When the dough was in position in the jar, the latter was submerged in a water thermostat at a temperature of 28°C.

The outlet tube of this device was of small bore (about 3 mm. i. d.) and led out of the thermostat and through a rubber bulb with valves into the absorption vessel. This rubber bulb was periodically compressed in such a way as to set up a more or less continuous movement of gases through the system. The absorption vessel was a test tube, 25 mm. i. d., provided with a two-hole stopper for the inlet and outlet tubes. The inlet tube, which conducted the gases containing CO_2, passed nearly to the bottom of the absorption vessel, while the outlet tube terminated flush with the inner face of the stopper. The outlet tube passed directly to the mason jar containing the dough. In using this device the atmosphere in the system was first freed from CO_2 by circulating the gases through a tube partially filled with moist soda-lime. This soda-lime tube occupied the same relation to the device as the absorption vessel which has just been described, and the circulating gases could be diverted through it by a simple system of cocks. With the gases circulating by periodic compression of the bulb, the cocks were then set so that the gases were led into the absorption vessel, the contents of which had been adjusted to a pH of 7.8. A stop-watch was then started and the time required for the hydrogen-ion concentration of the solution in the absorption vessel to increase to a pH of 7.0 was noted. The reciprocal of the time in seconds accordingly constituted a convenient measure of the comparative rate at which the dough in the cylinder was losing carbon dioxide. These values through the 240-minute fermentation period are recorded graphically in Figure 2 as Curve D. The values thus recorded are not absolute measures of the quantity of CO_2 lost by the dough. In fact, no effort was made to determine by this means either the volume or the weight of CO_2 which diffuses from the dough per unit of time. The values are merely comparative, and represent rate and not quantities of CO_2 lost from the dough. This may be made plainer by drawing an analogy from the speedometer of an automobile. The ordinary speedometer registers the rate of travel at any particular instant of time, which reading corresponds to the values obtained through the use of this modified Osterhout apparatus and recorded in Curve D. The speedometer also indicates the distance traveled, a quantity and not a rate factor, which, in the case of these studies of dough, finds its analogy in the record of

the quantity of CO_2 lost, as measured in the first apparatus that was described, and expressed graphically in Curve C.

A typical set of data resulting from the application of the Osterhout method to the study of a patent flour dough is given in Table I. Column 5 of this table records the time in seconds to effect a definite change in hydrogen-ion concentration of the solution in the absorption vessel. The reciprocal of these values multiplied by 10^3 are given in the sixth column of this table, and these data are plotted as Curve D in Figure 3. It is evident from a study of the graphs in Figure 3 that the change in rate of loss of CO_2 occurs suddenly and at the time when the break occurs in Curve C. The Osterhout method proves very convenient for this purpose, because not only is it comparatively simple of operation, but is very graphic. It is, moreover, unnecessary to begin to take readings with the dough immediately after the dough is set up in the mason jar. The practical baker can generally anticipate approximately the time when the dough is likely to cease expanding and can begin taking these readings some 20 or 30 minutes in advance of this period, and at 10- or 15-minute intervals thereafter until the change in rate occurs. Thus we note from the data in Table I that the time required for the color change in patent flour dough was fairly constant from the 110th to the 150th minute. Then there was a sharp decrease in time, or an increase in rate, which was fairly constant from the 160th to the 200th minute. In fact, the rate did not change greatly throughout the remainder of the period that the dough was under observation, 240 minutes. It is well to make two or three additional readings with this device after the change in rate has apparently occurred in order to secure confirmatory evidence.

One or two suggestions concerning the operation of this device may be of service to those who have occasion to use this method. For obvious reasons, the air in the closed system must be circulated continuously until time for making the first reading. The small quantity of carbon dioxide liberated during this period can be absorbed in a soda-lime tube. If only six or eight measurements are to be made with a dough, the same solution can be used in the absorption tube for all of these, as the original pH of 7.8 can be restored in this solution by aspirating carbon dioxide-free air through it. This can be conveniently accomplished by diverting the stream of circulating gases through a soda-lime tube situated just ahead of the absorption tube. By watching the change in the color of the indicator in the latter, the stream of circulating gases can be cut off from the absorption tube when its pH reaches 7.8, and the determination can then be made with

this solution. It is well to replace this with a fresh solution whenever a new series of observations is to be made, as its properties are evidently changed somewhat on repeated use.

As stiff sponges have been used in place of straight doughs to a considerable extent in bread making during the last few years, the question naturally arises as to how this method may be applied to the sponge system of fermentation. If a series of sponges is to be prepared which will have the same relative consistency, it is probable that this method of determining the optimum fermentation period may be applied equally as well to stiff sponges as to straight doughs. With sponges, it will doubtless be necessary to determine by previous experiments what fraction of the total fermentation period should be represented by the time to the explosive discharge of carbon dioxide, or the sudden change in the rate of loss of CO_2 as represented by the values obtained with the Osterhout apparatus. This fraction or proportion of time will be determined in part by the relative consistency of the sponges; the stiffer the sponge, the larger fraction of the total fermentation period represented up to this change in rate of loss of CO_2. Again, the interpretation of these measurements of rate of loss of CO_2 must depend in part upon the materials which are superimposed upon the basic dough formula. Thus flour improvers and malt extracts, when used in a dough, will modify the situation sufficiently that a slightly different factor may be necessary with any substantial addition of such materials. For example, if a diastatic malt is added to the dough it may be anticipated that this will incorporate an active protease in the material, which tends to hydrolyze and modify the properties of the gluten. Such doughs may require a shorter fermentation period than is the case when the active malt extract is not included. It will accordingly be necessary to regard the time of the change in rate of loss of CO_2 as a larger fraction of the total fermentation period when diastatic malts are used in the formula.

In other words, it is evident that a factor must be worked out for a particular practice in fermentation, and that a straight dough, made in the simplest possible fashion with water, sugar, salt, and yeast, in addition to the flour, constitutes a convenient control for working out the desirable factor when other ingredients are superimposed upon the simple dough formula. With the simple straight dough the time from mixing to the change in rate of loss of CO_2 may, in our opinion, constitute 60% of the total fermentation period up to the time when the dough is molded and placed in the pans for the final proof. With the sponge process, or with the addition of other materials to the simple straight dough formula, this factor may be modified somewhat,

but a few experiments will indicate the extent of modification for a particular formula. The procedure is especially useful, however, in determining the comparative length of fermentation period required for different flours which are used in a formula that is otherwise standardized. It will, in such instances, serve to show the proportional decrease or increase in the length of the fermentation period required when changes are made in the class and grade of flour used in a particular formula.

Summary

Two devices are described for conveniently measuring the rate of loss of carbon dioxide from fermenting bread doughs. The first method involves two determinations, in one of which the expansion of the dough plus the loss of carbon dioxide gas is registered, while in the second only the expansion of the dough is recorded. The difference between these values represents the quantity of carbon dioxide lost from the dough, which, when plotted against time, gives a curve representing the comparative rate of carbon dioxide loss. In the second device, involving modifications of the Osterhout apparatus, merely the rate of carbon dioxide loss is observed. The values thus determined are, however, convenient criteria of the stage of fermentation. After a lapse of 100 to 180 minutes, depending upon the characteristics of the flour and other ingredients of the dough, a sudden increase in the rate of loss of CO_2 will be observed. The comparative time required to effect this change in rate affords a convenient measure of the properties of a flour used in a standard formula, and may be correlated with the optimum fermentation period for flours under observation.

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CALCULATION OF ABSORPTION TO ANY MOISTURE BASIS

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The calculation of absorption to any moisture basis differs from that of protein or ash because the inherent moisture of the flour itself represents a partial per cent absorption.

Absorption is frequently reported on the basis of the moisture content of the flour as tested, or, if pounds of dough per barrel are reported, the calculation is made on that basis and not on the basis of 13.50% of moisture. As flour is ordinarily scaled and packed on a 13.50% moisture basis and as samples may easily vary from 10 to 15% moisture, considerable error is involved in this calculation.

With a desire to make less difficult the accurate comparison of the absorptive properties of flours at different moisture contents, the writer has advanced what he believes is a correct formula and a rapid graphical method of its application.

A. Let us suppose that 100 grams of a certain flour with 10% moisture content takes up 60 grams of water. Then, at 10% of moisture,

$$\text{Absorption} = \frac{60}{100} \times 100 = 60\%$$

B. If, without affecting its absorptive qualities, this flour were dried until entirely free of water, there would be 100 — 10 or 90 grams of flour which, upon adding water, would take 10 grams to bring it up to 10% moisture, plus 60 grams more, or 70 grams altogether. As in this case the sample was 90 grams of moisture-free flour,

$$\text{Absorption} = (60 + 10) \times \frac{100}{90} = 77.7\%$$

which means that 100 grams of the same flour with 0% moisture will absorb 77.7 grams of water.

Now, assume the above case to be known, and calculate the absorption of the flour at 10% moisture. At 10% moisture there will be 100 — 10 or 90 grams of dry flour in a 100-gram sample. Then, on a moisture-free basis, this amount of flour would absorb

$$\frac{90}{100} \times 77.7 \text{ grams} = 70 \text{ grams of water.}$$

To bring this 90 grams of dry flour to a 10% moisture content, 10 grams of water must be added. As this 90 grams of flour can hold

only 70 grams of water, and if 10 grams of this is added to the flour to bring to a 10% moisture basis, the flour will absorb only 60 grams more of water.

Therefore, the percentage absorption of the flour at 10% moisture content is:

$$\left(77.7 \times \frac{90}{100}\right) - 10 = 60\%$$

which is the original case (A).

Following this line of reasoning, this general formula may be written:

Having found absorption A′ of a flour sample, at the moisture M′, to calculate the absorption A at any desired moisture M:

$$A = \left[(A' + M') \times \frac{100-M}{100-M'}\right] - M$$

where A, A′, M, and M′ are expressed in percentages.

Calculation by this formula, however, would be somewhat tedious. The graph offers a ready and convenient solution.

As this is a linear equation, a straight line graph will be obtained by substituting known values for A′, M′, and M and solving for the corresponding value of A.

Three tables of values obtained in this way are given below:

1. Assume A′ = 58% when M′ = 13.50%,

M	A
9.50	65.4
11.50	61.7
12.50	59.9
13.50	58.0
14.50	56.2

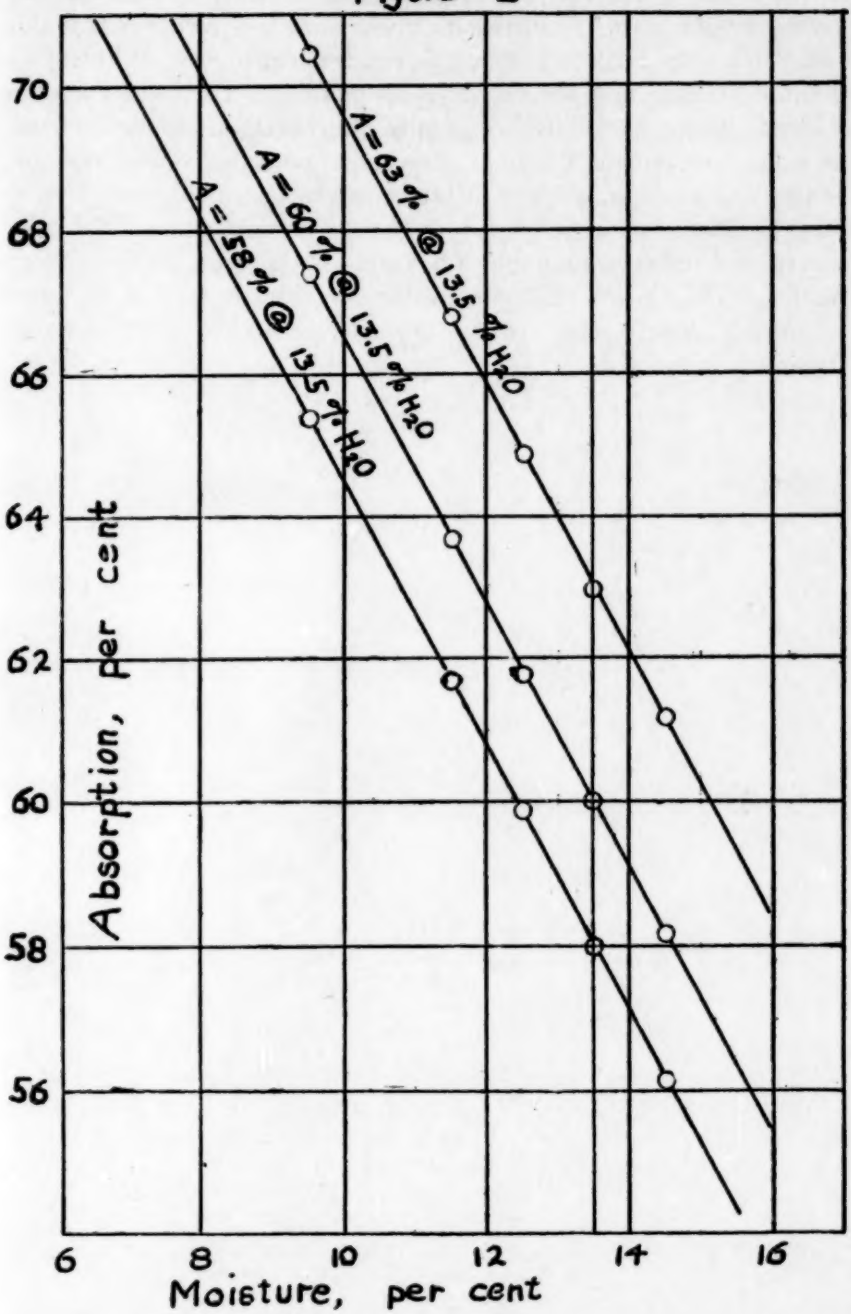
2. Assume A′ = 60% when M′ = 13.50%,

M	A
9.50	67.4
11.50	63.7
12.50	61.8
13.50	60.0
14.50	58.2

3. Assume A′ = 63% when M′ = 13.50%,

M	A
9.50	70.5
11.50	66.8
12.50	64.9
13.50	63.0
14.50	61.2

Figure 1


70
68
66
64
62
60
58
56
Absorption, per cent
6
8
10
12
14
16
Moisture, per cent
A = 63 % @ 13.5 % H2O
A = 60 % @ 13.5 % H2O
A = 58 % @ 13.5 % H2O

These values are shown plotted in the figure, and, as expected, they lie on straight lines. Furthermore, these lines are parallel. It is this fact that makes the graphical solution convenient to use. With such a graph containing any one set of values plotted as a straight line, it is a simple matter, having experimentally determined an absorption value of a flour containing a certain percentage moisture, to find the corresponding absorption for any other percentage moisture. This is done by placing the edge of a protractor, or straight edge, at the point determined and revolving until it has the same slope as the line already plotted. The desired absorption value can then be read at the point where the straight edge crosses the moisture line to which the conversion is to be made.

THE IDENTITY OF GLUTEN PROTEINS FROM VARIOUS WHEAT FLOURS

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Introduction

Regarding the present status of our knowledge and understanding of the factors which influence baking strength, an excellent and up-to-date historical review with literature citations has been offered in a very recent publication by Sharp and Gortner (1923). This gives a comprehensive account of the many viewpoints from which the subject has been investigated, and of the conflicting results which have frequently been obtained by different workers.

Altho there is lack of agreement among authorities with regard to the importance of certain factors having a possible bearing upon the chemistry of baking strength, no one appears to doubt the importance of gluten quality, less significance being attached to gluten quantity than formerly.

What is the basis of gluten quality and how may it be measured? Important information bearing upon this question may be briefly summarized as follows, details and references being amply furnished in a paper by Sharp and Gortner (1923) : Glutens of varying quality have varying physical properties, but it has been found extremely difficult satisfactorily to interpret these differences, or to express them in simple and quantitative terms. Gluten consists chiefly of two distinct proteins, glutenin and gliadin. Possible influence of the ratio of gliadin to glutenin on gluten quality has frequently been investigated. The same has been true of the actual quantity of gliadin. Such investigations, taken in the aggregate, have given contradictory and unconvincing results, and it is now known that the earlier methods for the quantitative estimation of gliadin and glutenin were inaccurate. Furthermore, it is now fairly well established that the gliadin-glutenin ratio does not vary as much as was formerly supposed, being usually not far from 1 :1. Wood (1907), Blish (1916), and Cross and Swain (1924), after examining the products of hydrolysis of gluten proteins from different wheats, found that glutens from different wheats probably do not vary appreciably with respect to the relative amounts of the various amino acids of which these proteins are composed.

As differences in gluten quality can not be accounted for on the basis of differences in chemical composition, a number of investigators

have attempted to account for gluten quality variations through the application of modern principles of colloid chemistry, for gluten is an emulsoid colloid. Prominent among these workers are Upson and Calvin (1916), Lüers and Ostwald (1920), Gortner and Doherty (1918), and Sharp and Gortner (1923). These investigators all agree that gluten quality is closely associated with colloidal properties, and that hydration capacity gives a reliable index to these so-called colloidal properties. Upson and Calvin (1916) conclude from water imbibition studies with gluten discs immersed in dilute solutions of electrolytes, that gluten quality is dependent upon *extent* of hydration, which in turn depends on the nature and amount of electrolytes with which the gluten is associated. Lüers and Ostwald substantially confirm Upson and Calvin (1916), using viscosimetric data. Gortner and Doherty (1918), and Sharp and Gortner (1923), as a result of detailed studies, believe that *rate* of hydration is more important than *amount* of hydration, and are of the opinion that this rate of hydration is determined by colloidal properties which are inherent in the protein glutenin. It is their opinion that gluten quality increases in direct proportion with rate of hydration, and that an index to gluten quality may be furnished by appropriate viscosimetric procedure.

Woodman (1922), after studying certain optical properties of the gluten proteins from two flours of different sources and varying quality, found that while the gliadins of the two flours were identical, the glutenins differed appreciably in specific rotatory powers as well as in their respective racemization rates when dissolved in sodium hydroxide. He concludes that altho glutenins may be identical as to nature and amounts of the amino acids which their respective molecules contain, they differ in molecular configuration (arrangement in which the amino acids are linked together) and that this is quite likely to be the basic cause of variations in flour strength. This conclusion falls in line with Sharp and Gortner's discovery that glutenin is the one gluten protein responsible for variations in colloidal properties.

Experimental

This investigation was undertaken with two main objects in view. One was to ascertain whether or not unexplainable (to the authors at any rate) differences in the baking qualities of certain Nebraska wheats could possibly be accounted for by differences in the molecular configuration of their respective glutenins, following Woodman's (1922) procedure and reasoning. The other and the more important object was to subject Woodman's idea to further test, as his conclusions, while appearing to offer a plausible and possible explanation for

differences in the physical properties of glutenins, are apparently based on but two preparations of glutenin, one from a strong Canadian wheat and the other from a weak English wheat.

Seven samples of pure glutenin and three of gliadin were examined in the course of this investigation. Three of the glutenin samples, as well as the gliadin samples, were carefully prepared and purified in this laboratory, following the usual methods. They may be described as follows: Preparations No. 190 represent glutenin and gliadin, respectively, from a sample of very high protein Kanred wheat produced in Lincoln County, Neb., but of poor baking quality; No. 281, from a sample of Marquis wheat grown in Scotts Bluff County, Neb., of fairly good protein content and of excellent baking quality; and "Polish," a sample of Polish wheat, of unknown origin, spring habit, high in protein, the gluten of which had very little gas-retaining capacity. This wheat has almost no commercial baking value, but was selected to represent the most extreme instance available of a poor quality wheat. In addition to these three samples of glutenin and gliadin respectively, four samples of pure glutenin were furnished from material left over from an investigation of the amino acid distribution in wheat proteins by Cross and Swain (1924) at Stanford University.[1] The original sources of these four glutenins are described by Cross and Swain as follows: "The sample 'Idaho' is a straight flour made from a hard wheat from that state. 'Patent' is their (the Sperry Flour Company's) regular, high patent, family flour made from a mixture of wheats. 'Club' is a straight flour made from pure Club wheat, a soft wheat from California, while 'Fortyfold' is a straight flour made from this variety grown in Washington." Baking data on these flours are not given, but it may be inferred that "Idaho" and "Patent" are superior in baking strength to "Club" and "Fortyfold."

These seven samples of glutenin and three of gliadin were examined with respect to their optical rotatory powers when dissolved in various solvents, as appreciable differences in specific rotatory power are believed to indicate differences in chemical configuration when the possibility of variation in actual chemical composition is ruled out, as it appears to be in the case of the gluten proteins. In all cases, solutions in dilute alkali were made and kept for several days in an incubator at 37°, rate of racemization in each sample being determined by noting specific rotations of the solutions at intervals. With samples 190, 281, and "Polish," the specific rotations of the glutenins and gliadins in other solvents were also determined. A Schmidt and

[1] The kindness of Dr. R. E. Swain, of Stanford University, in placing these samples at the disposal of the writers, is herewith gratefully acknowledged.

Haensch polarimeter with one decimeter tube was used in all instances, and readings were made at about 20°C. In spite of the fact that scrupulous care was taken in the preparation and purification of all protein samples, a very slight opalescence sometimes made initial readings in alkaline solutions very difficult. This usually cleared up after a day or so, altho by this time considerable racemization had always occurred. As in 1 and 2 per cent protein solution the readings in a 1-decimeter tube are multiplied by 100 and 50 respectively, to give specific rotation, it is readily seen that a slight error in polarimeter reading becomes considerably magnified. Many duplicate readings were made, and it is felt that the data presented in the following tables are convincing enough to warrant definite conclusions. All solutions were made approximately 1 or 2 per cent with respect to protein content, and total nitrogen was determined in aliquots of each solution. The actual amount of protein in each solution was then estimated on the basis of its total nitrogen, and specific rotations were corrected accordingly.

Table I shows specific rotations of 2 per cent glutenin solutions in .5N NaOH, at definite intervals. The samples are divided into two groups, as the time intervals for one group are not the same as those for the other, on account of unavoidable circumstances.

When the data in Table I are compared for similar time intervals, it is apparent that within the limits of probable error the gluteninș show no significant differences in optical behavior in .5N NaOH, with the exception of "Polish," which gives appreciably low readings throughout. In order to check this point further, racemization studies were made with 190, 281, and Polish in 1 per cent solution in .1N NaOH. The specific rotations of these three glutenins in 2 per cent solution in 50 per cent acetic acid were also determined. The results are shown in Tables II and III.

TABLE I

RACEMIZATION DATA FOR 2% GLUTENINS IN .5N NaOH; SPECIFIC ROTATIONS AT DEFINITE TIME INTERVALS

Hours	190	281	Polish	Hours	Idaho	Patent	Club	Fortyfold
3	—73.8°	?	?	4	?	?	?	?
17	—61.9	—58.2°	—53.4°	21	—60.2°	—58.1°	—58.8°	—58.8°
41	—53.2	—50.7	—46.5	45	—53.0?	—50.8	—53.4	—52.7
65	—47.9	—46.9	—41.6	69	—45.8	—47.0	—48.4	—48.4
113	—42.4	—41.0	—36.6	213	—38.5	—37.7	—34.7	—34.8
136	—40.7	—38.9	—33.1	357	—36.1	—30.6	—32.9	—34.5
160	—37.8	—36.5	—31.2	515	—27.4	—27.6	—27.8	—28.3
185	—36.2	—33.7	—30.0					
209	—35.2	—31.4	—27.8					
281	—32.3	—30.8	—28.2					

TABLE II

SPECIFIC ROTATIONS AT DEFINITE TIME INTERVALS FOR 1% SOLUTIONS OF GLUTENIN IN .1N NaOH

Hours	190	281	Polish
2	—76.2°	—76.3°	—70.5°
25	—73.6	—69.8	—68.5
49	—71.2	—70.3	—66.5
73	—68.9	—68.9	—64.5
121	—67.7	—68.3	—64.2
145	—64.9	—66.9	—62.3
169	—65.0	—63.6	—61.3
194	—64.9	—64.7	—59.6
218	—61.9	—62.6	—56.4
338	—61.8	—62.6	—56.5

TABLE III

SPECIFIC ROTATIONS OF 2% GLUTENINS IN 50% ACETIC ACID

	190	Polish	281
Specific rotation	63.9°	60.1°	63.9°

Data offered in Tables II and III substantiate the evidence presented by Table I, which is to the effect that glutenin from Polish wheat differs consistently in optical rotatory power from glutenins 190 and 281, whose glutenins are identical in this respect. Altho, as previously mentioned, flour 281 was vastly superior to flour 190 in baking quality, the difference cannot be ascribed to differences in the molecular configurations of their respective glutenins.

The glutenins from Idaho, Patent, Club, and Fortyfold flours are shown in Table I to be practically identical, not only with each other, but with those of 190 and 281. However, since the 2 per cent solutions were difficult to read in the early stages of racemization, it was decided to check the results shown in Table I by examining the behavior of 1 per cent solutions in .25N NaOH. The results of this examination are set forth in Table IV.

TABLE IV

SPECIFIC ROTATIONS AT DEFINITE TIME INTERVALS FOR 1% GLNTENINS IN .25N NaOH

Hours	Idaho	Patent	Club	Fortyfold
8	—80.4°	—79.3°	—80.3°	—81.0°
24	—70.4	—73.4	—72.6	—72.5
49	—67.4	—67.0	—66.6	—67.6
97	—60.2	—61.2	—59.7	—61.5
121	—58.2	—59.0	—58.0	—58.2
169	—54.0	—55.5	—55.0	—54.0
217	—51.3	—48.0	—53.7	—52.4

The figures for the four glutenins, in Table IV, show even better agreement than those for the same glutenins in Table I, and constitute fairly conclusive evidence that the glutenins from these four different types of wheat are identical. It may be concluded, therefore, from the

data shown in the preceding tables that the glutenins from six out of seven flours from widely different types and varieties of wheat are identical. The glutenin which was found to differ slightly from the others was from a very unusual variety which has little commercial baking value.

Woodman (1922) found that altho his two glutenins differed in molecular configuration, the corresponding gliadins were identical, and no one has ever offered any evidence to the contrary. Gröh and Friedl (1914) found that gliadins from strong and weak flours had the same physical constants. Since, as Woodman indicated, the possible existence of more than one gliadin is not precluded, carefully purified gliadins from 190, 281, and "Polish" flours were accordingly submitted to tests similar to those reported for the glutenins.

TABLE V

SPECIFIC ROTATIONS AT DEFINITE TIME INTERVALS FOR GLIADINS

2% Gliadin in .1N NaOH				2% Gliadin in .5N NaOH			
Hours	190	281	Polish	Hours	190	281	Polish
2	—107.7°	—106.5°	—102.2°	2	—109.9°	—110.6°	—104.6°
23	—105.8	—105.8	— 99.4	18	—101.0	—101.9	— 93.8
47	—105.8	—105.8	— 99.1	43	— 91.4	— 91.2	— 86.8
71	—104.4	—104.4	— 97.8	67	— 86.4	— 84.7	— 80.7
95	—103.4	—103.1	— 96.4	91	Lost	— 82.1	— 76.7
119	—103.1	—102.9	— 96.1	116	"	— 78.7	— 72.1
168	—102.5	—102.5	— 94.8	236	"	— 68.2	— 60.4

TABLE VI

SPECIFIC ROTATIONS 2% GLIADINS IN 70% ALCOHOL AND IN GLACIAL ACETIC ACID

Solvent	190	281	Polish
70% alcohol.....	—100.0°	—97.4°	—93.6°
Glacial acetic.....	— 85.8	—85.5	—79.5

From Tables V and VI the conclusions may be fairly drawn that the gliadins 190 and 281 are identical, while the Polish gliadin differs from the other two in the same manner as the Polish glutenins differed from glutenins 190 and 281. Racemization is very slow in the case of 2 per cent gliadin in .1N NaOH, as compared with .5N NaOH, altho in both cases the rate is slightly faster with Polish gliadin than with the other two. It should be stated here also that the Polish wheat gliadin differed noticeably from the other two with respect to physical properties noted during its preparation and purification, being much less coherent and elastic than the gliadins 190 and 281.

General Discussion

From the experimental results which have been presented and discussed it is evident that the glutenins of flour produced from several commercially important United States wheats of widely different variety and quality are for all practical purposes identical in

molecular configuration as well as in chemical composition. It seems highly improbable that differences in the respective flour "strengths" of our commercially important wheats can ever be attributed to differences in the chemical configurations of their respective glutenin molecules. This conclusion, based on studies of seven samples of pure glutenin from seven different types of wheat, is in disagreement with the conclusion of Woodman (1922), based on two samples. Woodman's strong Manitoba flour glutenin had, in .5N NaOH, an initial specific rotation of —93.0 degrees, while his weak English flour glutenin showed a corresponding value of —74.0 degrees. If these figures indicate differences in molecular configuration which influence flour strength, then one must infer that the higher numbers (disregarding the minus sign) should go with the stronger flours. With six of the seven glutenin samples reported upon in this paper, however, the optical behavior in .5N NaOH is in each case almost identical with that of Woodman's *weak* flour glutenin, altho at least two of these glutenins were from flours of excellent baking strength. It seems, then, that differences in the physical or "colloidal" properties of glutens must be due either to differences in the states of aggregation of the respective glutenins, as indicated by the work of Sharp and Gortner (1923), or to profound influences of electrolytes or of minute quantities of either unknown or unrecognized substances on the glutenin, as evidenced by the work of Upson and Calvin (1916) and Lüers and Ostwald (1920). The discovery that the optical rotation of Polish wheat gliadin differed appreciably from the gliadins of 190 and 281, constitutes the first instance (so far as the writers are aware) of any evidence that gliadins from different wheats are ever other than strictly identical chemically.

It is probable, of course, that the standard methods of preparing and purifying glutenin and gliadin (particularly glutenin) affect slight molecular changes, but no one has ever reported alterations such as would be likely to affect the results of this study.

Summary and Conclusions

1. Seven samples of pure glutenins from widely different types and varieties of American wheats were examined with respect to their respective racemization rates in alkaline solution, in order to discover possible differences in chemical configuration such as are suggested by Woodman (1922), who based his conclusions upon a study of two samples in this way. The specific rotations of three of these glutenins in acetic acid were also noted. Six of the seven samples, which included flours of both high and low baking strength, were found to be identical. One glutenin which was from Polish wheat, an unusual variety of wheat having extremely poor baking value, differed from the others.

2. Three samples of pure gliadin were examined by the same methods as were used with the glutenins. Two were identical, and here again the Polish wheat gliadin differed slightly from the other two. Similar results were obtained from comparisons of the specific rotations of the gliadins in alcohol and in glacial acetic acid, respectively.

3. This work indicates that instances may be found in which both glutenins and gliadins vary slightly in their respective molecular configurations.

4. It is highly improbable that variations in the respective flour strengths of our commercially important wheats can ever be attributed to differences in the chemical configurations of their respective glutenin molecules. This is in disagreement with the conclusions of Woodman (1922).

5. Differences in physical or colloidal properties of glutens appear to be due either to different states of molecular aggregation or to influences of electrolytes or other agents at present unknown.

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FRENCH SCHOOL OF MILLING[1]

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The milling industry plays a very important rôle in France, as the average Frenchman requires from 500 to 600 grams of bread.

Until the first half of the 19th Century, the flour was manufactured in France exclusively by small mills, which are scattered all over the country, and numbered about 37,000.

It is hardly forty years since large milling companies have come into being, and have formed a well organized industry of great importance. Since the beginning of the 19th Century, French mills have been chiefly interested in perfecting their mechanical devices so as to produce a whiter flour, which was very much in demand by the baking trade.

In spite of the large amount of scientific work done and the many papers published on cereal chemistry, the French miller did but very rarely avail himself of the results of this scientific research.

In the last few years, however, the situation has changed somewhat; large mills have begun to recognize the value of laboratory control, and have installed laboratories possessing a small test mill and an experimental bakery. In Paris there is a large mill which in addition to its milling and baking laboratory has also a very complete research laboratory, which is supervised by competent chemists. Of course, the maintenance of such laboratories is rather costly and can be afforded by only large mills.

Until the present time, milling was a craft which in France could be learned only by actually working through the various departments of a mill, or by studying in foreign milling schools. The National Milling Association of France has now opened a school for milling, with which is connected a chemical laboratory, a test mill, and an experimental bakery. Thus this institution provides a center for the teaching of the milling craft and for research in cereal chemistry.

This milling school had been planned for quite a number of years but could actually be installed only recently after the millers had pledged their financial assistance. Under the direction of Mr. H.

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EDITOR'S NOTE: This is the first of a series of articles to be published describing the several foreign and American institutions devoted to instruction and research in the field of milling and baking chemistry and technology.

Chasles, President of the National Milling Association of France, and in collaboration with engineers, teachers, and milling technologists, the school was organized, and its program worked out. All initial expenses incurred through the equipment of the school and the laboratories were met partly by a subvention granted by the State Department of Technical Education, partly by private donations, and partly by the National Milling Association. The necessary funds for the upkeep of the school are to be derived from the tuition fees and the fees charged by the service laboratory.

The courses will begin on October 13, 1924, and are open to any one possessing a good general education.

A practical and theoretical examination will be held at the end of the course, and a degree of milling engineer will be awarded to all successful entrants to this examination. The school and the service laboratories are located in the Parisian university district near the Pantheon, in the building of the "Societe d' Hygiene Alimentaire et d' Alimentation rationell de l'Homme."

The school will include in its course the study of the following subjects: milling, cereals, chemistry, technology, entomology, mechanical and electrical engineering, law, and milling legislations. These subjects will, of course, all be treated from the point of view of the milling industry.

The staff of teachers is composed of well known cereal chemists and milling technologists. The pratical milling is conducted in a city mill (Moulin de l'assistance Publique de Paris) under the guidance of members of the teaching staff of the school, and the head miller of the mill.

The laboratories, which occupy a whole floor, are used for three purposes:

1. For the instruction of the students in the routine analysis of flours.
2. For research work on flour and bread manufacture.
3. For an analytical service laboratory which will charge a nominal fee for its services, this fee to be reduced for members of the national organization. This service has been functioning since June last.

The laboratories are quite spacious and are provided with the most up-to-date equipment.

The experimental mill and bakery are housed in the same room. An automatic mixer holding from 2 to 3 kgs. of flour, mixes the doughs for the baking tests. Two ovens take care of the baking; one is a gas-heated oven (Perkins) and has a baking surface of 1.80 M. by 1.20 M., the other is electrically heated, and somewhat smaller.

The experimental mill is composed of a break mill, a reducer, and a Bunge plansifter.

The analytical methods used in the service laboratory have been compiled by Mr. Arpin and are the result of many years experience, their object being to give the millers a relative baking value of their flours. All new analytical procedures published in foreign countries, particularly in the United States and England, are also carefully examined.

A close collaboration is maintained between the laboratories of the milling school and the institute of agricultural research, both institutions being located in the same building.

This brief exposè gives an idea of the work which the National Milling Federation of France has undertaken since about two years ago, and from which resulted the foundation of the present School of Milling.

Through this foundation the milling industry has brought into being a long-needed institution, which promises to provide in the future discoveries that will still further perfect the process of milling. This institution will thus be the natural clearing house for all technical progress made in the milling industry of France.

THE QUALITY OF GLUTEN OF FLOUR MILL STREAMS AS DETERMINED BY THE VISCOSITY OF WATER SUSPENSIONS

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(Read at the Convention, June 13, 1924)

The quality of gluten has been measured and expressed in various ways by different cereal chemists. In the majority of cases this property has been determined by washing out the wet, crude gluten from a simple flour dough in the conventional manner and observing the force required to stretch and break the more or less elastic crude gluten. In such cases the chemist found it necessary to express his observations in rather general terms, and ordinarily resorted to the use of adjectives. Observations have led to the conclusion that in many instances the opinion of the chemist was influenced by the quantity as well as the physical properties of the mass of wet, crude gluten. Personal judgment is called into play to such an extent as to make it difficult for several experimenters to arrive at the same findings in examining the same flour, or for the same analyst to check, in the case of duplicate determinations made at different times. Several mechanical devices have been described for use in measuring the elasticity of gluten and of dough, certain of which have been referred to by Bailey and LeVesconte (1924) and by Sharp and Gortner (1924). None of these have come into extensive use in America.

Sharp and Gortner (1924) discussed at length the colloidal properties of wheat gluten, and devised a viscometric method for quantitatively estimating the relative quality of gluten without removing it from the flour in which it is contained. This method and the calculations involved have been described in convenient form by Gortner (1924). In these and other similar studies, however, the criterion of the acceptability of the test applied has been the results of baking trials conducted by experienced flour testers; and until some new procedure is generally accepted for evaluating these important properties of flour, we doubtless must continue to employ the baking test in connection with the other supplementary tests which are being suggested.

Millers and mill chemists are aware that there is considerable variation in the baking properties and other characteristics of the various

streams of flour produced in the roller milling process. Extended reference to these properties can be found in the literature, notably in publications of Teller (1896), Wiley et al. (1898), Snyder (1904), Swanson (1912), Swanson, Willard, and Fitz (1915), Bailey and Collatz (1921), Bailey and Peterson (1921), and others. These studies have served to establish that the several streams of flour produced in a roller mill differ in a variety of ways, and that each stream has peculiar and distinctive properties and characteristics. It appeared desirable to establish the extent of variation in the properties of wheat gluten in these streams as determined by the viscometric procedure of Sharp and Gortner. Such a study should indicate whether or not the gluten from different portions of the wheat kernel, as separated in the gradual reduction process in roller milling, varies substantially, and whether such variations could account for the observed differences in baking properties of the flour.

In conducting this study, the flour streams as produced in the Minnesota State Experimental Flour Mill, Minneapolis, were used. These streams had been previously examined and partially described by Bailey (1923) in a report of the experimental mill, which report included a fairly complete description of the process and a diagram of the mill flow. The method for the determination of viscosity of washed and acidulated flour suspensions, as described by Gortner (1924), was followed in detail, no significant modifications of this procedure being introduced. In all instances the viscosity was determined using four ratios of flour to water, viz., 12, 15, 18, and 21 grams of flour per 100 cc. of the final suspension. The logarithm of concentration was plotted as abscissa against the logarithm of viscosity as ordinates and in all cases the points fell approximately on a straight line. Using the method of least squares and substituting in the equation presented by Gortner, the tangent (b) which this plot forms with the axis of abscissa was calculated. These data for each of the flour streams are presented in Table I. The individual graphs are not shown because they add little to the significance of the data which are not established by the constants (b) calculated in the manner just described. For convenience, in the table and in the subsequent discussions the tangent of this angle will be referred to as the "quality factor." It is evident from these data that considerable variation exists in the quality of gluten in the several flour streams. The break flours, as a group, are comparatively low, the 5th break rating lowest on the basis of this test. In the 3rd, 4th, and 5th break flours the high concentration of gluten (protein) more than compensated for the low quality of gluten, and large loaves of satisfactory texture resulted from baking

these flours. Obviously the percentage of gluten must not be overlooked in considering the desirability of such flours in a mill mixture. The sizings flour rated medium in point of gluten quality, and the middlings flours rated uniformly high. The gluten quality factor recorded by the tailings flour was surprisingly high, but when the tests of this flour were repeated essentially the same values were again found.

In addition to these viscosity measurements, baking tests of the several flours were conducted in the laboratories of the Cargill Elevator Company, and the volumes of the loaves (in cc.), together with the texture ratings, are shown in Table I. It will be observed that the quality factor is not positively correlated with the loaf volume or texture. On scanning the table, it is evident that the loaf volume may be affected not alone by the quality of the gluten, but by the percentage of gluten in the flour. Thus it is apparent that in several instances flours with a relatively low quality factor baked into a large loaf of bread, but in such instances the percentage of protein, which approximately parallels the percentage of gluten, was relatively high.

In order to compensate for the variation in the percentage of gluten, as indicated by the protein content, the percentage of crude protein was multiplied by the quality factor and the resulting product divided by the loaf volume, as in the equation:

$$\frac{\text{Crude Protein} \times \text{Quality Factor}}{\text{Loaf Volume}} = K \qquad (b)$$

If loaf volume is determined largely by the concentration and quality of gluten, such a calculation should tend to give a constant value in the case of all samples examined. It is recognized that such a calculation assumes a constant diastatic activity, and the authors recognize that flours are not constant in this property, hence in many instances the values secured by calculation following this equation deviate substantially from the mean of the constants. Observations made at the experimental mill, as yet unpublished, apparently establish that there are significant variations in the diastatic activity of the mill streams, the highest diastatic activity being encountered in flours milled from streams containing the largest proportion of germ or embryo.

In order to give constant values in all cases, this calculation must also assume that if gluten qualities were uniform the loaf volume would be a linear function of protein content, that is, that the loaf volume would increase directly with each unit of increase in the percentage of crude protein. This latter we know is not the case, it being established by data reported by Bailey (1924) that the relation is not

a linear one and that the higher the protein content the less the effect of each unit increase in percentage of protein on the loaf volume. To correct for this changing effect of increasing protein content, would necessitate the incorporation of an exponential factor in the equation and make for a complicated calculation.

A third source of error in the simple equation for calculating K, is to be found in the omission of the loaf texture rating. The latter is an arbitrary score assigned by the persons scoring the loaves and hence may be objected to as lacking precision. It does, however, have a pronounced bearing on the strength of flour samples, since flours which bake into large loaves of poor texture are not regarded as favorably as those yielding loaves rating high in both particulars. Arbitrary texture scores were assigned the loaves baked from these flour streams, and on introducing these scores into the denominator of the fraction, multiplying loaf volume by the texture score, there was a tendency in the direction of narrowing up the range in the numerical value of the constant (K). There were two outstanding exceptions to this rule, however: the 6th middlings flour with its high quality factor and low texture score, and the 5th break flour, with a low quality factor and fairly high texture score.

TABLE I

RELATION BETWEEN GLUTEN QUALITY AND FLOUR STRENGTH

Flour stream	Crude protein (N×5.7) per cent	Loaf volume cc.	Texture score	Quality factor (b)	K
1st break flour	12.03	2435	98	2.03	.00978
2nd " "	11.20	2600	96	2.13	.00875
3rd " "	13.32	2500	96	2.02	.01069
4th " "	15.11	2610	94	1.61	.00929
5th " "	15.22	2620	96	1.47	.00855
Sizings flour	10.22	2370	90	2.16	.00932
1st middlings flour	11.24	2335	96	2.56	.01232
2nd " "	10.92	2255	98	2.68	.01298
3rd " "	11.08	2360	98	2.61	.01223
4th " "	11.72	2300	96	2.74	.01396
5th " "	11.55	2250	96	2.33	.01196
6th " "	11.57	2430	92	3.06	.01455
Tailings flour	11.40	2440	90	2.74	.01280
Bran and shorts duster flour	12.52	1940	80	1.57	.01012

Excluding these two cases, it seems evident from these data that the viscometric method affords a useful means of determining the comparative quality of gluten in the streams of flour from a modern roller mill. If certain other variables, notably the diastatic activity, and an exponential value to compensate for the variations in loaf volume with varying protein content, were included in the equation, a fairer test of the value of this quality factor might be had.

Summary

Flour streams resulting from the gradual reduction process employed in roller milling vary substantially in gluten quality when the latter is determined by the viscosity of washed and acidulated water suspensions of the flour. Middlings flours rated highest and break flours lowest in gluten quality. The latter contained higher percentages of gluten, however, which tended to compensate for the inferior quality of the gluten.

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